US007620153B2

(12) **United States Patent**
Qiu et al.

(10) **Patent No.: US 7,620,153 B2**
(45) **Date of Patent: Nov. 17, 2009**

(54) CAGE FOR X-RAY TUBE BEARINGS

(75) Inventors: **Liangheng Qiu**, Waukesha, WI (US); **Myles Standish Peterson, II**, Delanson, NY (US); **Carey Shawn Rogers**, Brookfield, WI (US); **Dalong Zhong**, Niskayuna, NY (US)

(73) Assignee: **General Electric Company**, Schenectady, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 22 days.

(21) Appl. No.: **11/747,562**

(22) Filed: **May 11, 2007**

(65) **Prior Publication Data**

US 2008/0279335 A1 Nov. 13, 2008

(51) **Int. Cl.**
H01J 35/10 (2006.01)
(52) **U.S. Cl.** **378/132**; 378/119
(58) **Field of Classification Search** 378/132–133, 378/119
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,150,398	A *	9/1992	Nishioka et al.	378/132
5,696,808	A *	12/1997	Lenz	378/121
5,752,773	A *	5/1998	Rosado et al.	384/527
5,773,147	A	6/1998	Sundberg	
6,585,483	B2 *	7/2003	Feest	415/122.1
6,726,993	B2	4/2004	Teer et al.	
2004/0179762	A1 *	9/2004	Doll et al.	384/492
2005/0276530	A1 *	12/2005	Chen et al.	384/536

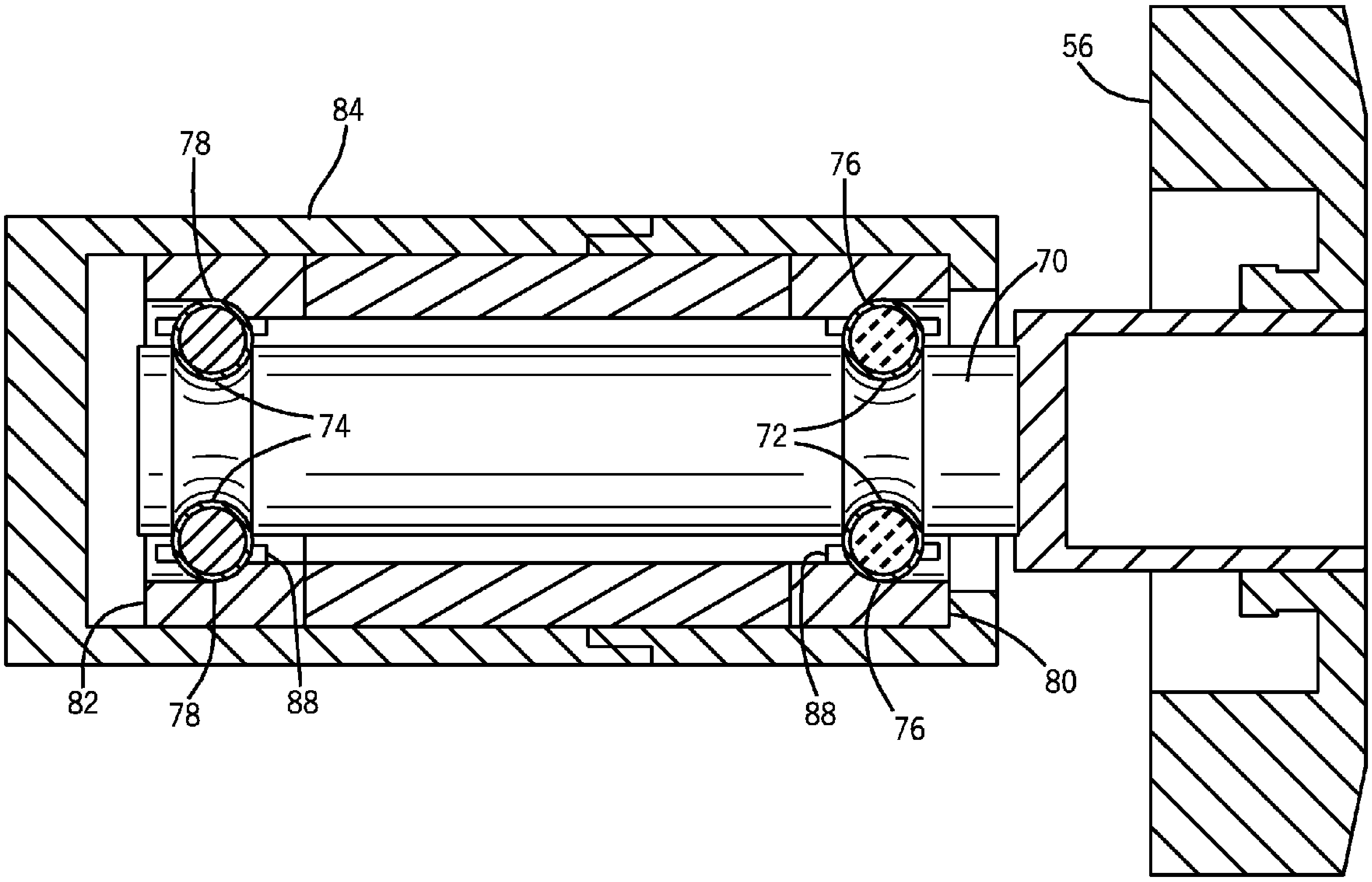
* cited by examiner

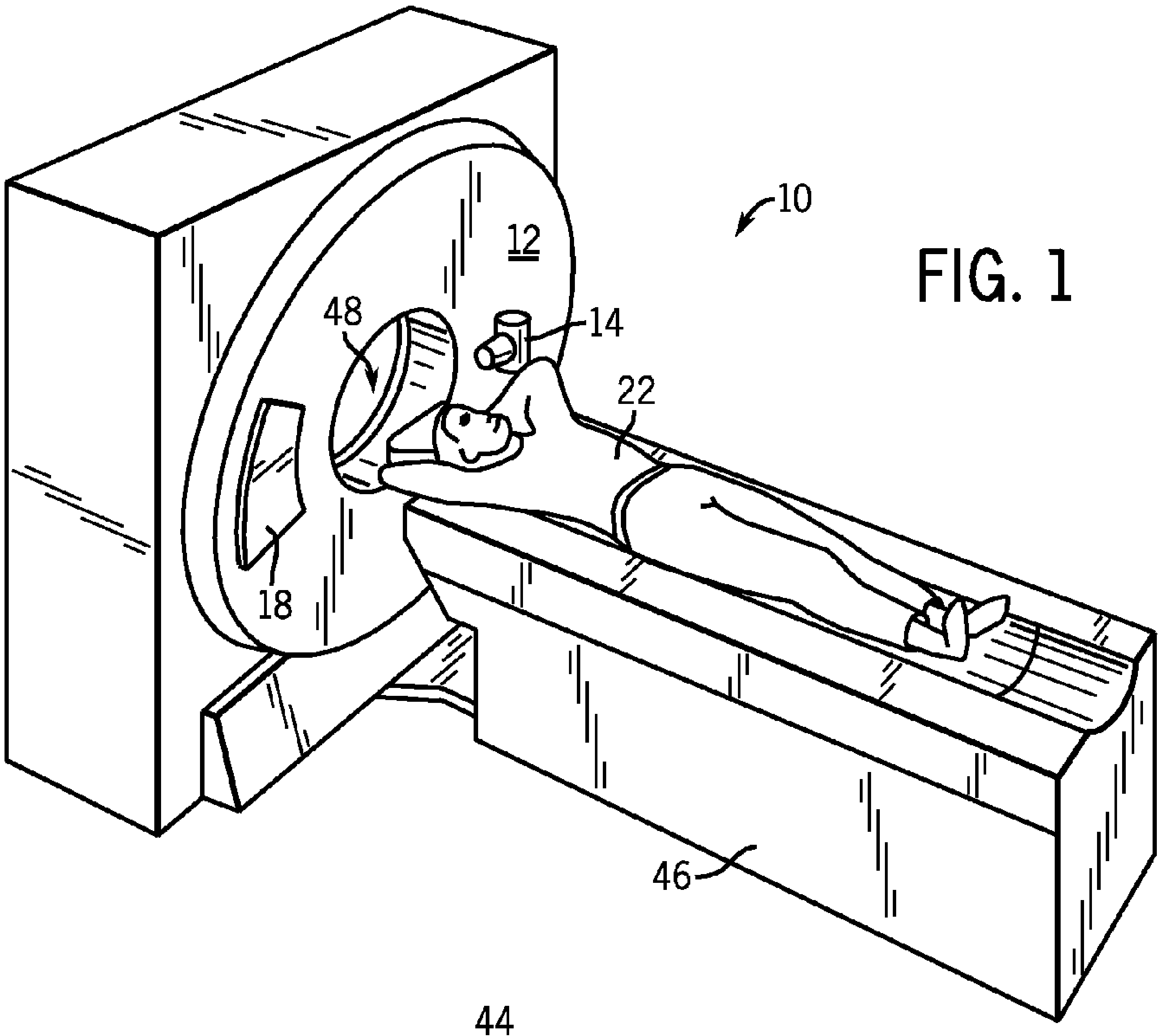
Primary Examiner—Hoon Song
(74) *Attorney, Agent, or Firm*—Ziolkowski Patent Solutions Group, SC

(57) ABSTRACT

A bearing assembly mounted in an x-ray tube includes a bearing race and a plurality of bearing balls positioned adjacent to the bearing race. The plurality of bearing balls are positioned within a bearing cage. The bearing cage is configured to evenly space the bearing balls within the bearing cage and prevent contact between adjacent bearing balls, thereby eliminating the problems of skidding wear and dynamic impact load between adjacent bearing balls in the bearing assembly.

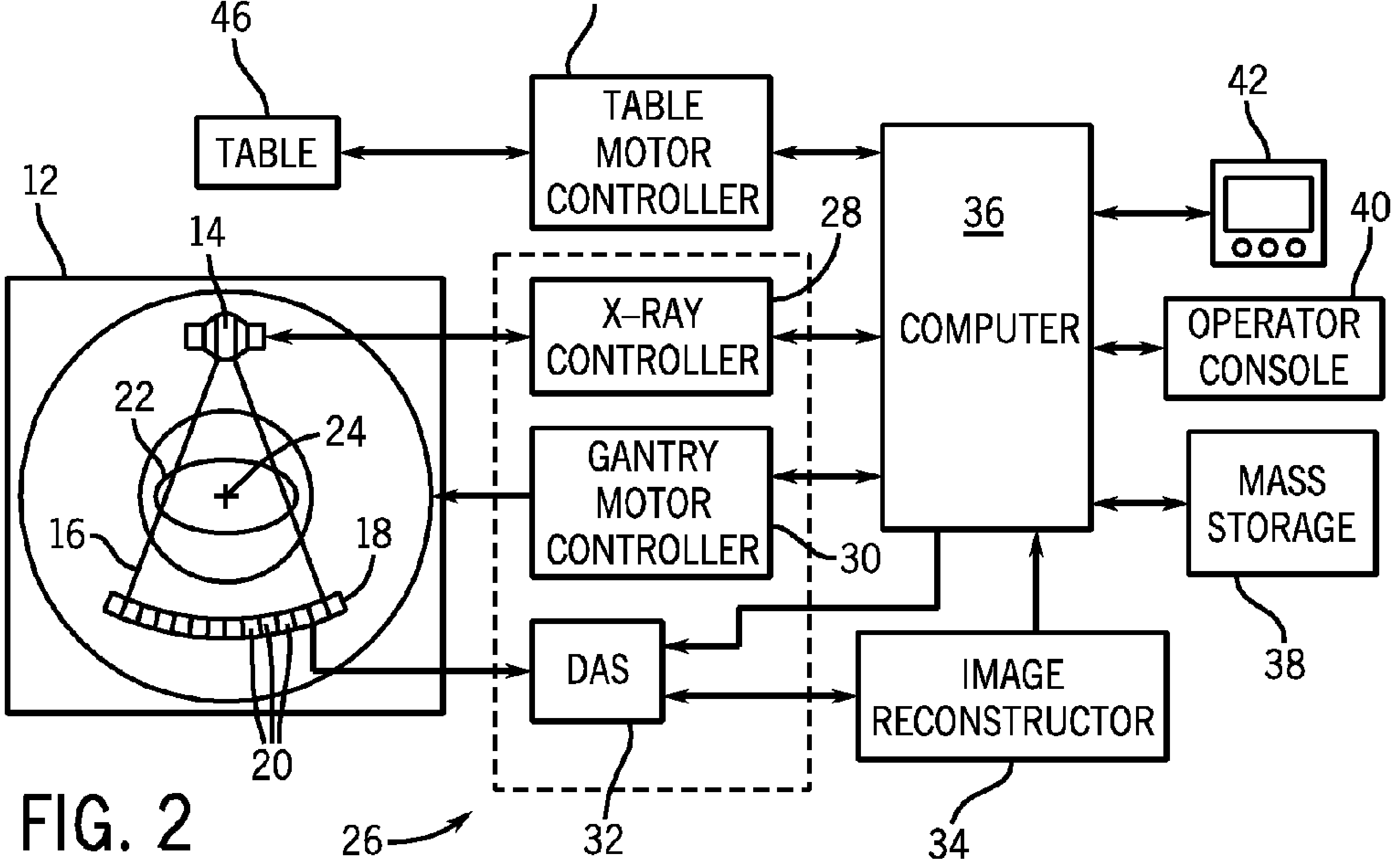
14 Claims, 6 Drawing Sheets





10
12
14
48
22
18
46

FIG. 1



46
TABLE
44
TABLE MOTOR CONTROLLER
42
12
14
28
X-RAY CONTROLLER
36
COMPUTER
40
OPERATOR CONSOLE
22
24
16
18
GANTRY MOTOR CONTROLLER
30
MASS STORAGE
38
DAS
IMAGE RECONSTRUCTOR
20
26
32
34

FIG. 2

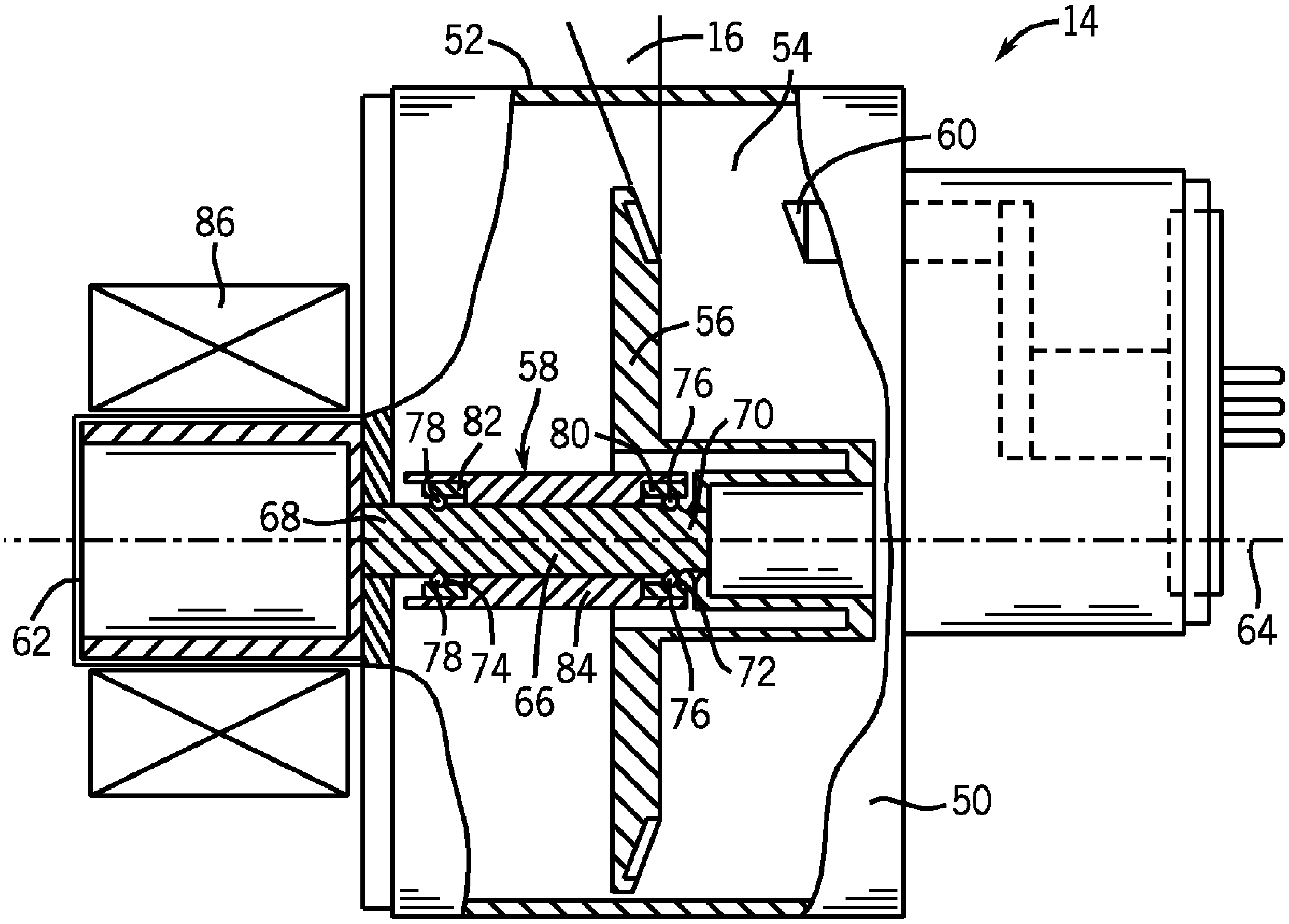


FIG. 3

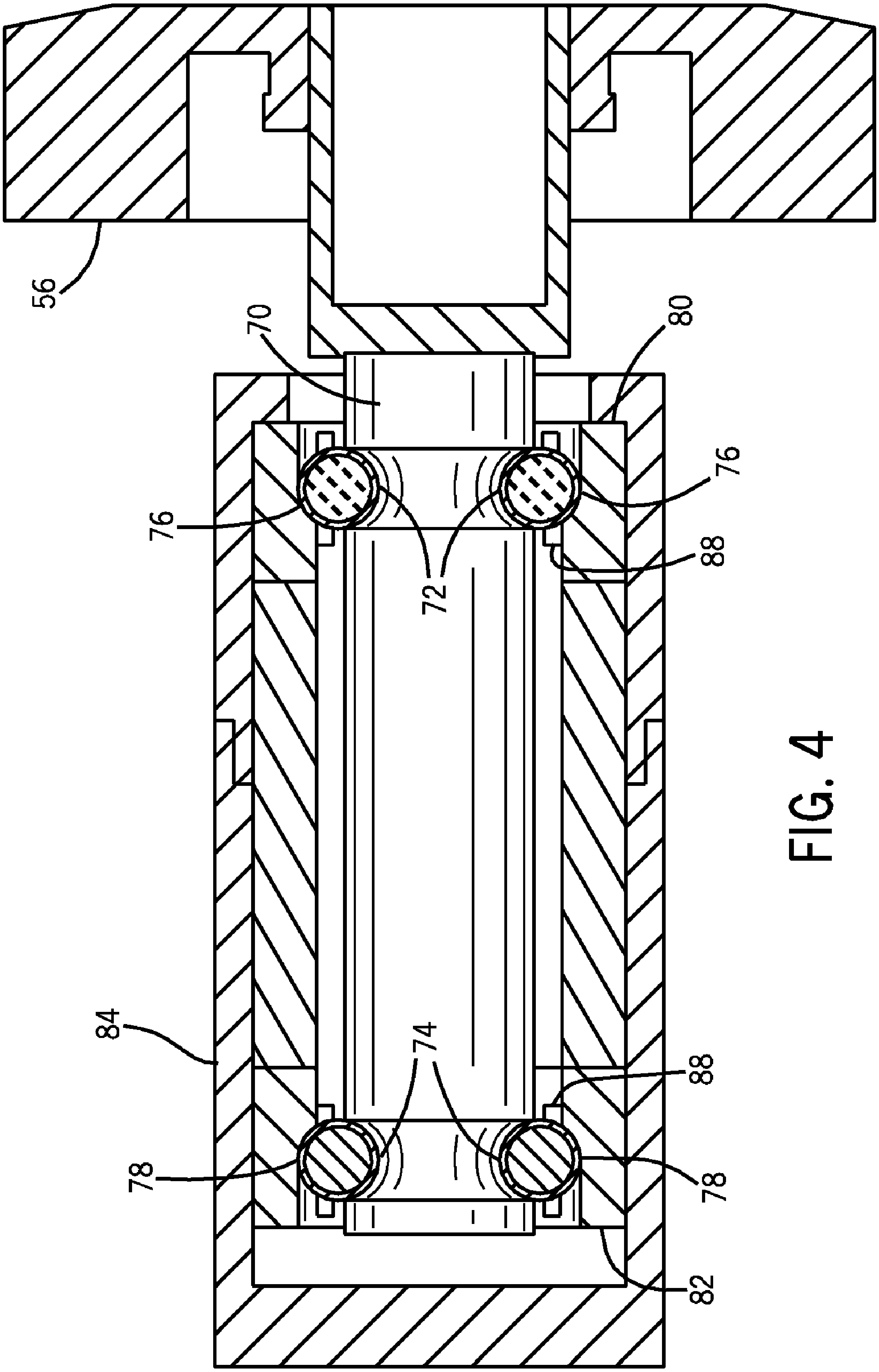


FIG. 4

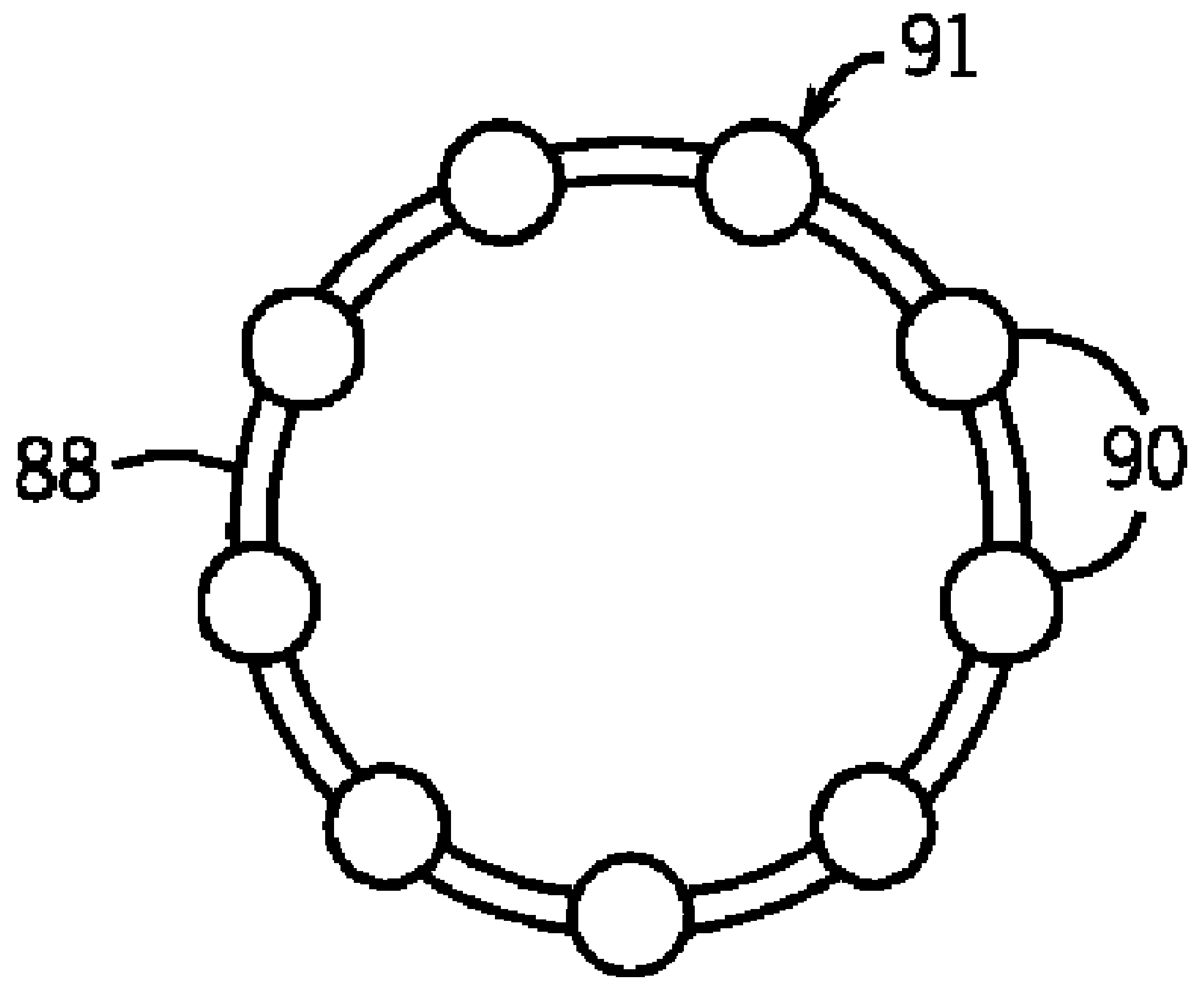


FIG. 5

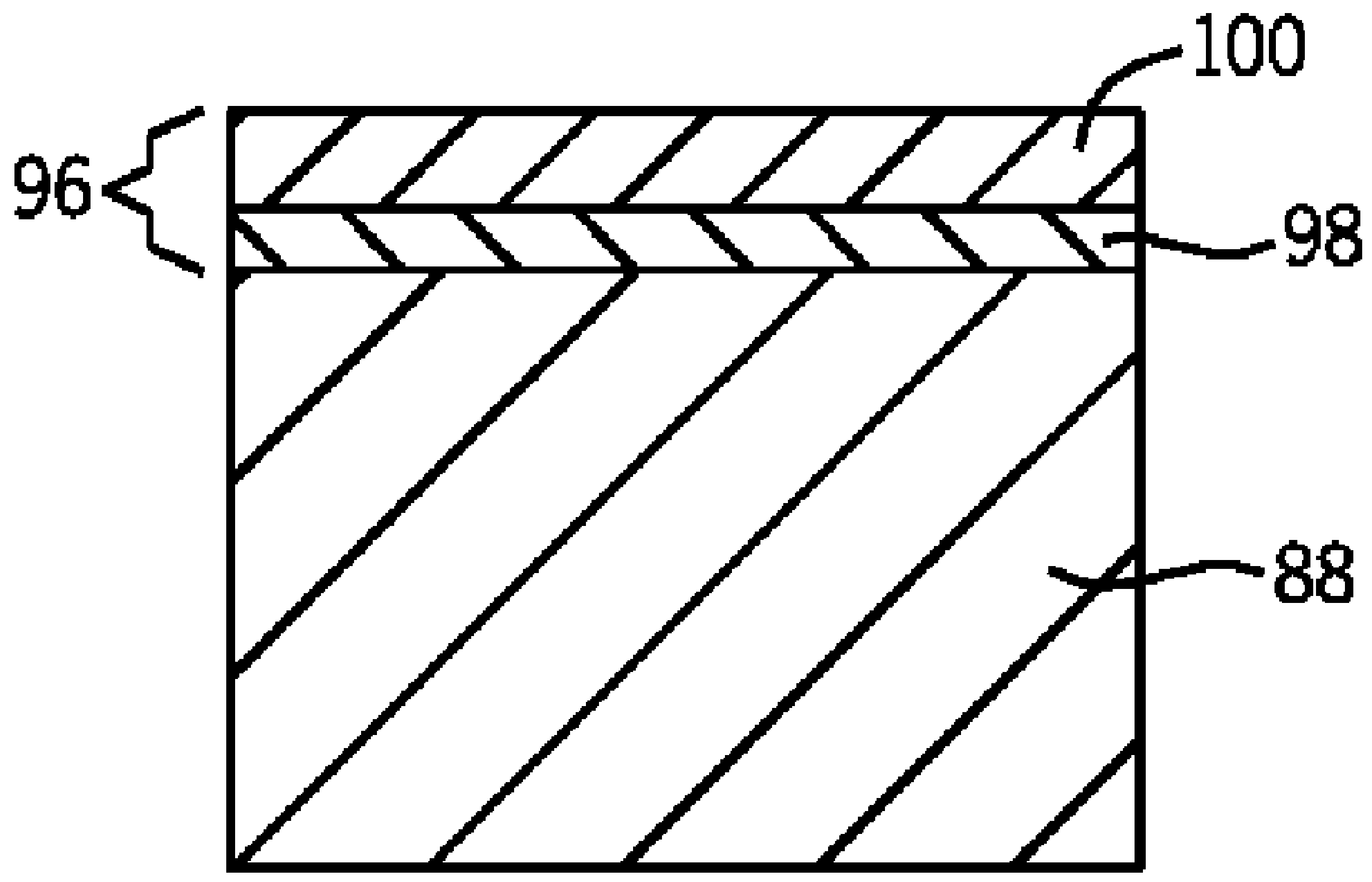


FIG. 6

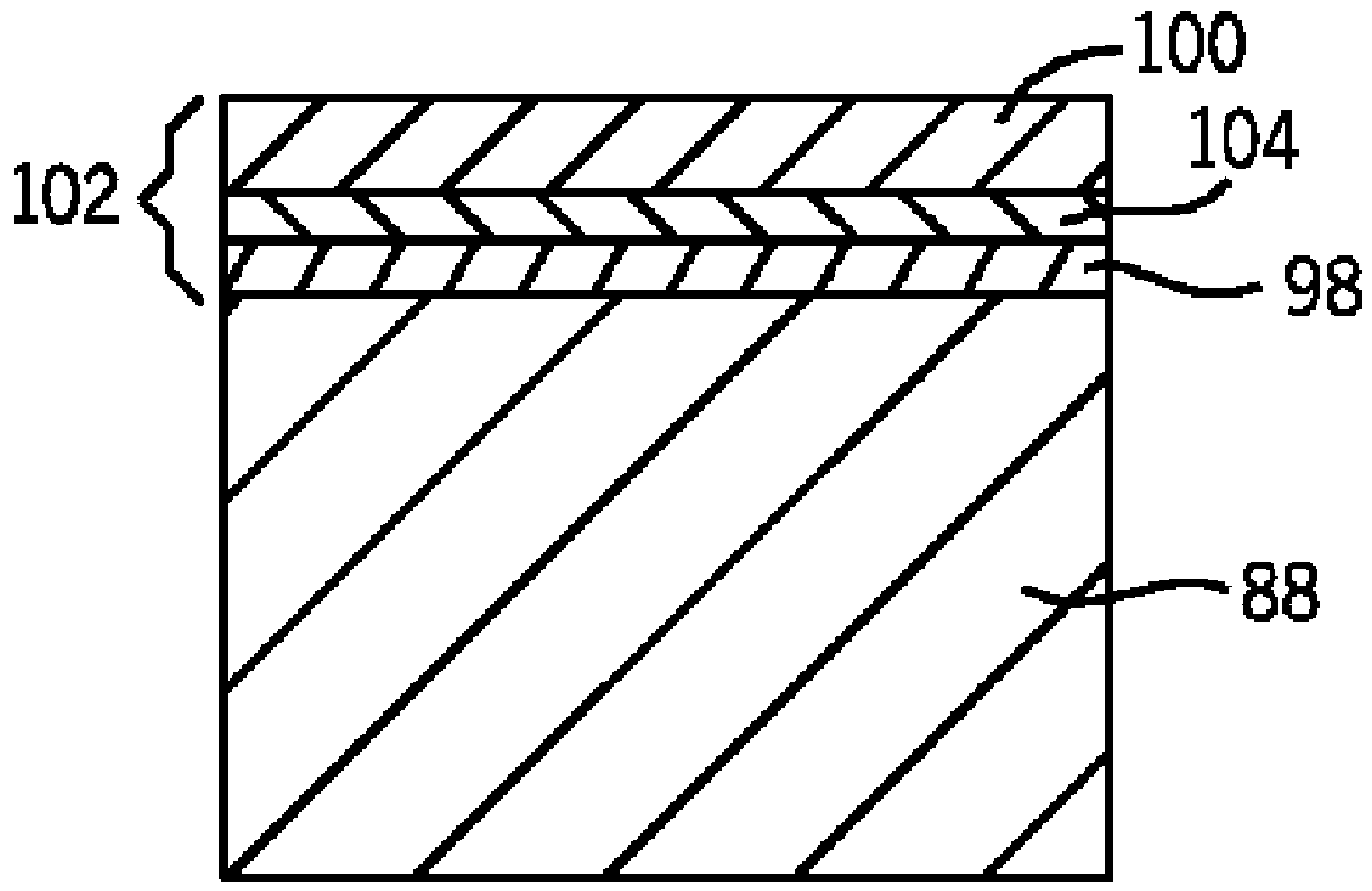


FIG. 7

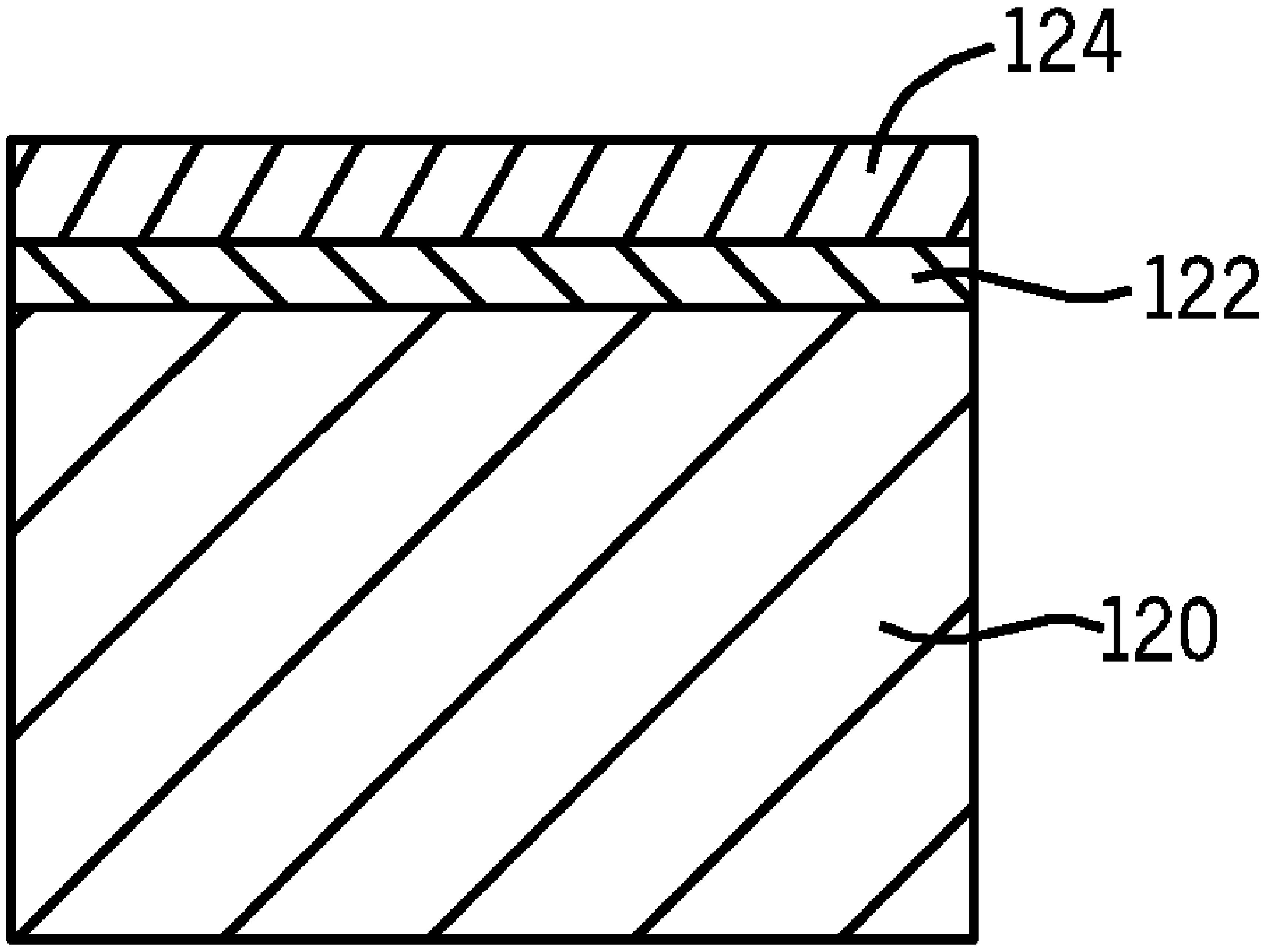


FIG. 8

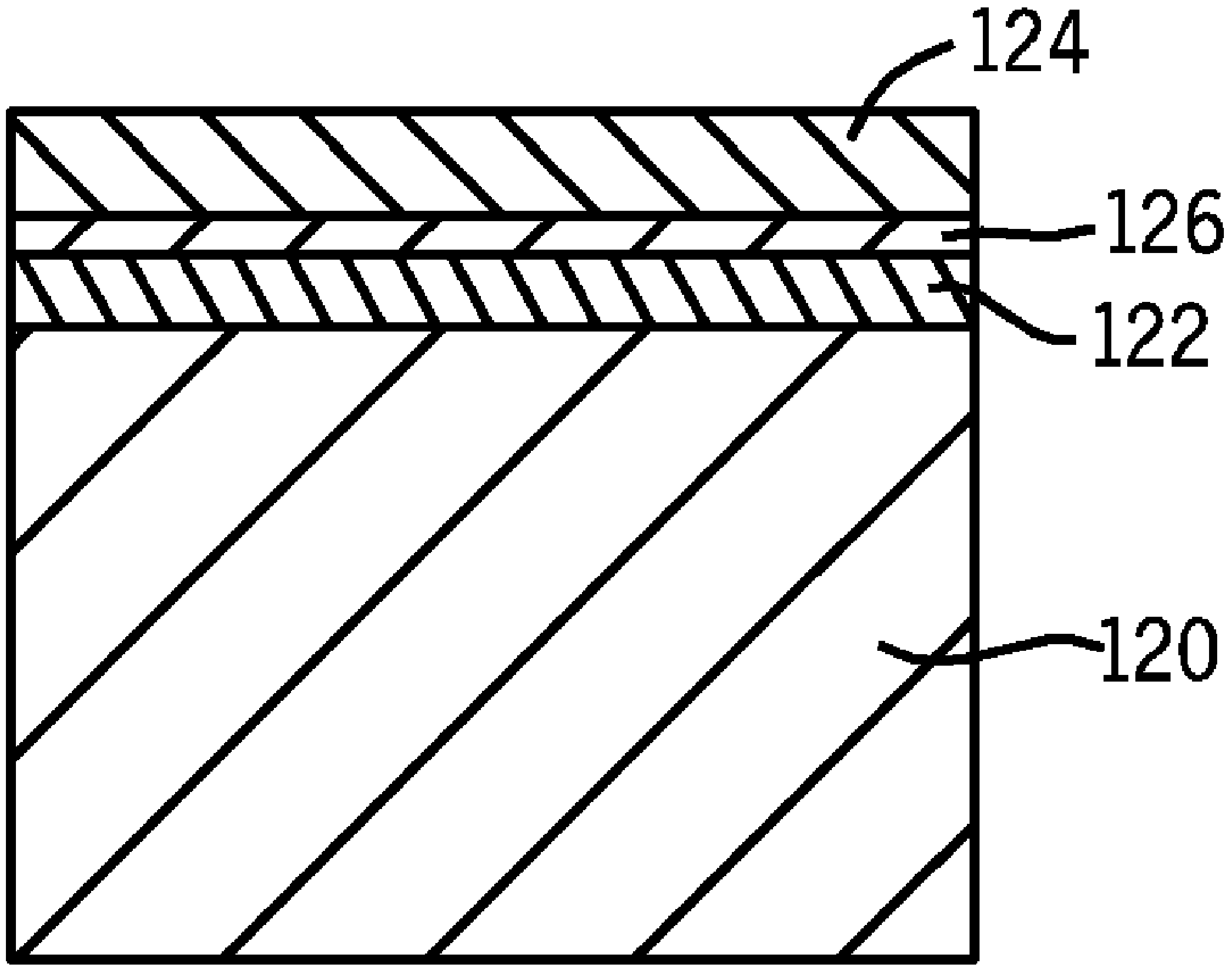


FIG. 9

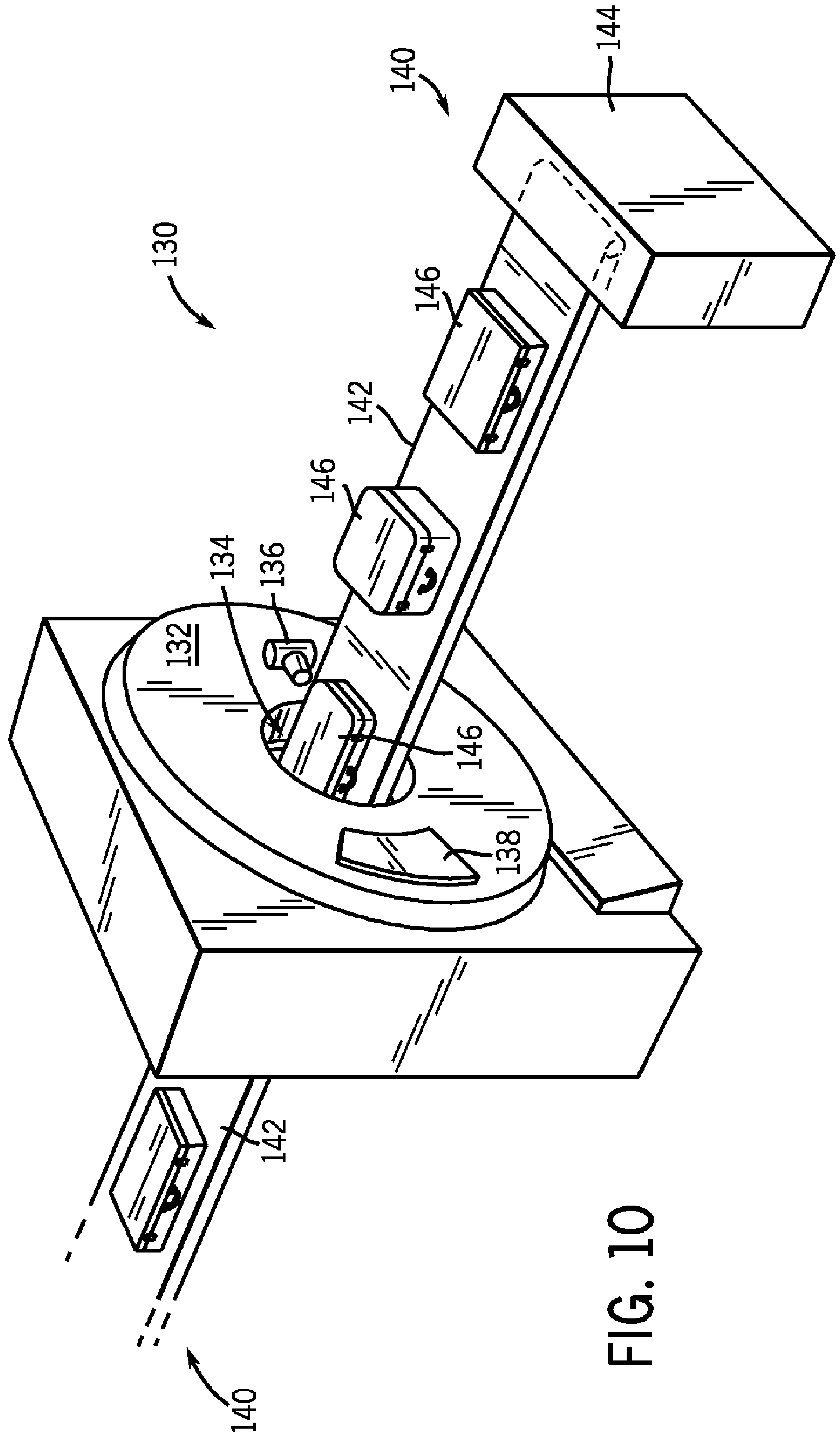


FIG. 10

CAGE FOR X-RAY TUBE BEARINGS

BACKGROUND OF THE INVENTION

The present invention relates generally to x-ray tubes and, more particularly, to an x-ray tube bearing assembly having a bearing cage therein.

X-ray systems typically include an x-ray tube, a detector, and a bearing assembly to support the x-ray tube and the detector. In operation, an imaging table, on which an object is positioned, is located between the x-ray tube and the detector. The x-ray tube typically emits radiation, such as x-rays, toward the object. The radiation typically passes through the object on the imaging table and impinges on the detector. As radiation passes through the object, internal structures of the object cause spatial variances in the radiation received at the detector. The detector then emits data received, and the system translates the radiation variances into an image, which may be used to evaluate the internal structure of the object. One skilled in the art will recognize that the object may include, but is not limited to, a patient in a medical imaging procedure and an inanimate object as in, for instance, a package in a computed tomography (CT) package scanner.

X-ray tubes include a rotating anode structure for the purpose of distributing the heat generated at a focal spot. The anode is typically rotated by an induction motor having a cylindrical rotor built into a cantilevered axle that supports a disc-shaped anode target and an iron stator structure with copper windings that surrounds an elongated neck of the x-ray tube. The rotor of the rotating anode assembly is driven by the stator. An x-ray tube cathode provides a focused electron beam that is accelerated across an anode-to-cathode vacuum gap and produces x-rays upon impact with the anode. Because of the high temperatures generated when the electron beam strikes the target, it is necessary to rotate the anode assembly at high rotational speed. This places stringent demands on the bearing assembly, which includes tool steel ball bearings and tool steel raceways.

Bearings used in x-ray tubes are required to operate in a vacuum, which precludes lubricating with conventional wet bearing lubricants such as grease or oil. X-ray tube bearing rolling elements (i.e., bearing balls) are typically coated with a solid layer, or tribological system, of a metal with lubricating properties, such as silver, lead, or lead-tin. The lubricating metal that coats the bearing balls helps to reduce friction between adjacent balls and between the balls and the raceway. Despite the lubricating metal coating, however, a large amount of friction and heating is present at contact points between the balls and the raceway. The operating conditions in the x-ray tube environment, where temperatures in the vacuum environment range from 300-500 degrees Celsius and stress levels on the bearing balls can exceed 2.5 GPa, creates yet additional challenges for the bearing.

Failure of a bearing in an x-ray tube is typically by wear of the plated silver and loss of the silver from a contact region between adjacent bearing balls and between the bearing balls and the raceway. Wear of the plated silver can occur because the balls in the bearing are not evenly spaced around the raceway and the ball-to-ball space positions are changed when the bearing is running. When a bearing ball is transitioned from a load zone to a non-load zone in the bearing, the ball rapidly moves out of the load zone and hits an adjacent ball due to load release. This load release results in a large impact load between adjacent bearing balls. The impact load damages a ball surface by causing indentations on the surface at the ball-to-ball contact point. Additionally, the rotation of adjacent bearing balls are opposite to one another. The rotational velocity of the ball surfaces, in inverse directions, creates high skidding torque and heat build-up when the adjacent balls contact one another. The high skidding velocities and internal heat created by ball-to-ball contact causes tremendous wear and lubrication damage so as to reduce bearing life. Thus, impact indentations, skidding wear, and heat build-up all serve to affect bearing performance and durability.

Therefore, it would be desirable to have a method and apparatus to eliminate the problems of skidding wear and dynamic impact load between adjacent balls in a bearing assembly. It would also be desirable to reduce bearing internal torque and minimize heat build-up so as to improve bearing performance and extend bearing life.

BRIEF DESCRIPTION OF THE INVENTION

The present invention provides a method and apparatus for positioning bearing balls in an x-ray tube bearing assembly that overcome the aforementioned drawbacks. A bearing cage is included in the bearing assembly that spaces the bearing balls within the bearing cage to prevent contact between adjacent bearing balls, thereby eliminating skidding wear and dynamic impact load between adjacent balls and reducing bearing internal torque and heat build-up.

According to one aspect of the present invention, a bearing assembly mounted in an x-ray tube includes a bearing race, a plurality of bearing balls positioned adjacent to the bearing race, and a bearing cage positioned about the plurality of bearing balls.

According to another aspect of the present invention, an imaging system includes an x-ray detector, an x-ray tube having a rotatable shaft, and a bearing assembly supporting the rotatable shaft. The bearing assembly further includes a bearing race, a plurality of rolling elements positioned adjacent to the bearing race, and a bearing cage configured to house the plurality of rolling elements.

According to yet another aspect of the present invention, an x-ray tube bearing includes a raceway having an inner race and an outer race, a retainer positioned between the inner race and the outer race at each of a first end and a second end of the raceway, and a plurality of bearing balls within the retainer.

Various other features and advantages of the present invention will be made apparent from the following detailed description and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings illustrate one preferred embodiment presently contemplated for carrying out the invention.

In the drawings:

FIG. **1** is a pictorial view of a CT imaging system that can benefit from incorporation of an embodiment of the present invention.

FIG. **2** is a block schematic diagram of the system illustrated in FIG. **1**.

FIG. **3** is a cross-sectional view of an x-ray tube useable with the system illustrated in FIG. **1**.

FIG. **4** is a cross-sectional view of a bearing assembly according to one embodiment of the present invention.

FIG. **5** is a cross-sectional view of a bearing cage according to one embodiment of the present invention

FIG. **6** is a partial cross-sectional view of a bearing cage having a combination coating according to an embodiment of the present invention.

FIG. **7** is a partial cross-sectional view of a bearing cage having a gradient coating according to an embodiment of the present invention.

FIG. **8** is a partial cross-sectional view of a base material having a combination coating according to an embodiment of the present invention.

FIG. **9** is a partial cross-sectional view of a base material having a combination coating according to another embodiment of the present invention.

FIG. **10** is a pictorial view of a CT system for use with a non-invasive package inspection system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The operating environment of the present invention is described with respect to the use of an x-ray tube as used in a computed tomography (CT) system. However, it will be appreciated by those skilled in the art that the present invention is equally applicable for use in other systems that require the use of an x-ray tube. Such uses include, but are not limited to, x-ray imaging systems (for medical and non-medical use), mammography imaging systems, and RAD systems.

Moreover, the present invention will be described with respect to use in an x-ray tube. However, one skilled in the art will further appreciate that the present invention is equally applicable for other systems that require operation of a bearing in a high vacuum, high temperature, and high contact stress environment, wherein a solid lubricant, such as silver, is plated on the rolling contact components. The present invention will be described with respect to a "third generation" CT medical imaging scanner, but is equally applicable with other CT systems, such as a baggage scanner.

Referring to FIGS. **1** and **2**, a computed tomography (CT) imaging system **10** is shown as including a gantry **12** representative of a "third generation" CT scanner. Gantry **12** has an x-ray tube **14** that projects a beam of x-rays **16** toward a detector array **18** on the opposite side of the gantry **12**. Detector array **18** is formed by a plurality of detectors **20** which together sense the projected x-rays that pass through a medical patient **22**. Each detector **20** produces an electrical signal that represents the intensity of an impinging x-ray beam and hence the attenuated beam as it passes through the patient **22**. During a scan to acquire x-ray projection data, gantry **12** and the components mounted thereon rotate about a center of rotation **24**.

Rotation of gantry **12** and the operation of x-ray tube **14** are governed by a control mechanism **26** of CT system **10**. Control mechanism **26** includes an x-ray controller **28** that provides power and timing signals to an x-ray tube **14** and a gantry motor controller **30** that controls the rotational speed and position of gantry **12**. A data acquisition system (DAS) **32** in control mechanism **26** samples analog data from detectors **20** and converts the data to digital signals for subsequent processing. An image reconstructor **34** receives sampled and digitized x-ray data from DAS **32** and performs high speed reconstruction. The reconstructed image is applied as an input to a computer **36** which stores the image in a mass storage device **38**.

Computer **36** also receives commands and scanning parameters from an operator via console **40** that has a keyboard. An associated cathode ray tube display **42** allows the operator to observe the reconstructed image and other data from computer **36**. The operator supplied commands and parameters are used by computer **36** to provide control signals and information to DAS **32**, x-ray controller **28** and gantry motor controller **30**. In addition, computer **36** operates a table motor controller **44** which controls a motorized table **46** to position patient **22** and gantry **12**. Particularly, table **46** moves portions of patient **22** through a gantry opening **48**.

FIG. **3** illustrates a cross-sectional view of an x-ray tube **14** that can benefit from incorporation of an embodiment of the present invention. The x-ray tube **14** includes a casing **50** having a radiation emission passage **52** formed therein. The casing **50** encloses a vacuum **54** and houses an anode **56**, a bearing assembly **58**, a cathode **60**, and a rotor **62**. X-rays **16** are produced when high-speed electrons are suddenly decelerated when directed from the cathode **60** to the anode **56** via a potential difference therebetween of, for example, 60 thousand volts or more in the case of CT applications. The x-rays **16** are emitted through the radiation emission passage **52** toward a detector array, such as detector array **18** of FIG. **2**. To avoid overheating the anode **56** from the electrons, an anode **56** is rotated at a high rate of speed about a centerline **64** at, for example, 90-250 Hz.

The bearing assembly **58** includes a center shaft **66** attached to the rotor **62** at first end **68** and attached to the anode **56** at second end **70**. A front inner race **72** and a rear inner race **74** of center shaft **66** rollingly engage a plurality of front balls **76** and a plurality of rear balls **78** (i.e., bearing balls), respectively, that function as rolling elements. Bearing assembly **58** also includes a front outer race **80** and a rear outer race **82** configured to rollingly engage and position, respectively, the plurality of front balls **76** and the plurality of rear balls **78**. Bearing assembly **58** includes a stem **84** which is supported by the x-ray tube **14**. Stator **86** drives rotor **62**, which rotationally drives anode **56**.

In addition to rotation of the anode **56** within x-ray tube **14**, the x-ray tube **14** as a whole is caused to rotate about gantry **12** at rates of, typically, 1 Hz or faster. The rotational effects of both the x-ray tube **14** about the gantry **12** and the anode **56** within the x-ray tube **14** cause the anode **56** weight to be compounded significantly, hence leading to operating contact stresses in the races **72**, **74**, **80**, **82** (i.e., a raceway) and bearing balls **76**, **78** of up to 2.5 GPa. Additionally, heat generated from operation of the cathode **60**, the resulting deceleration of electrons in anode **56**, and heat generated from frictional self-heating of the races **72**, **74**, **80**, **82** and bearing balls **76**, **78** to operate typically above 400 degrees Celsius.

To reduce the heat and wear generated by friction between adjacent bearing balls **76**, **78**, a bearing cage or retainer is included in bearing assembly **58**. As shown in FIG. **4**, bearing assembly **58** includes bearing cages **88** to house the plurality of front bearing balls **76** and rear bearing balls **78**, although it is also envisioned that only a single bearing cage **88** be included in the bearing assembly **58** to house either front bearing balls **76** or rear bearing balls **78**. Bearing cages **88** are included at both the first and second ends **68**, **70** of the bearing assembly **58** and are positioned between the front inner and outer races **72**, **80** and the rear inner and outer races **74**, **82**, respectively. Bearing cages **88** are positioned about the bearing balls **76**, **78** and are configured to prevent contact between adjacent balls. As shown in the detailed view of bearing cage **88** in FIG. **5**, the bearing cage **88** is configured to evenly space the individual bearing balls **90** within apertures **91** formed in the bearing cage **88**. As such, bearing cage **88** prevents impact load damage, skidding wear, and heat buildup that would occur were the bearing balls **90** allowed to make contact with one another. The alignment of the bearing balls **90** provided by bearing cage **88** also evenly distributes loads between the balls **90** associated with bearing rotation. Referring back to FIG. **4**, the bearing cage **88** also accurately guides the balls in the races **72**, **74**, **80**, **82** during rotation of the bearing assembly **58**.

The bearing cages **88** are formed of a material that possesses a high specific strength and is capable of operating in an extreme high temperature environment, such as the environment present during operation of an x-ray tube. In a preferred embodiment, bearing cages **88** are formed of a carbon-carbon composite material that can withstand operation in an x-ray tube environment. It is envisioned, however, that the bearing cages **88** can also be formed from other suitable materials, such as AISI 4340 steel, that contain desired strength and temperature characteristics. Carbon-carbon composites, in particular, display a number of physical properties that make it a suitable material for construction of the bearing cages **88** for use in an x-ray tube. First, carbon-carbon composites have a high specific strength at high temperature (up to 1000° C. in vacuum), which is suitable for the high temperature environment of the x-ray tube bearing assembly. Also, carbon-carbon composites have a low coefficient of thermal expansion, which is desirable to lower strain associated with the large temperature differentials experienced in x-ray tube operation. Additionally, carbon-carbon composite materials have a low density, which serves to reduce the centrifugal force caused by the bearing cages **88** and lessen wear between the bearing cage **88** and the raceways **72**, **74**, **80**, **82**, shown in FIG. **4**, as compared to denser materials. Finally, carbon-carbon composites have excellent heat transfer properties that help to reduce heat buildup in the bearing cages **88**.

Because of the high temperatures and high rotational speeds imposed on the bearing assembly by operation of the x-ray tube, according to another embodiment of the present invention, a coating may be applied to the carbon-carbon composite bearing cage **88** to allow it to operate more effectively by reducing part-wear and increasing lubricative properties. That is, a dry film or self-lubricating coating can be applied to bearing cage **88** for purposes of lubrication. Referring now to FIG. **6**, a partial cross-sectional view of a bearing cage **88** is shown. As shown therein, a combination coating **96** is applied to the base material (i.e., carbon-carbon composite) that forms the bearing cage **88**. The combination coating **96** includes a bonding layer **98** (i.e., interlayer) and a lubricant layer **100**. The bonding layer **98** is formed from a bonding material (i.e., an adhesion promoter) such as platinum, tungsten, molybdenum, chromium, nickel, silicon, copper, or titanium, although it is also envisioned that other suitable materials could also be used. The bonding layer **98** promotes adhesion between lubricant layer **100** and bearing cage **88** through a finite mutual solubility with the lubricant layer material and the base material of bearing cage **88**. Ti and W metals, for example, provide both mechanical adhesion provided through a deposition process and chemical adhesion between bearing cage **88** and lubricant layer **100**. In one embodiment, the bonding layer **98** is deposited on bearing cage **88** with a thickness from 10-100 nanometers so as to coat the bearing cage **88**. It is also envisioned that bonding layer can have a greater thickness, such as 5-20 microns for example, or alternatively, that an intermediate layer of 5-20 microns be applied to the thin 10-100 nm base bonding layer. Where bearing cage **88** is formed of a carbon-carbon composite, a thickness in the range of 5-20 microns for either bonding layer **98** or an intermediate layer can serve to, at least in part, fill-in irregularities that may be present on the carbon-carbon composite surface and present a smooth surface to which lubricant layer **100** can be applied. A smoother lubricant layer **100** will thus be formed, which may decrease wear in the bearing cage, extend bearing assembly life, and decrease subsequent machining costs. While specified thickness ranges for bonding layer **98** (and possibly an intermediate layer) have been set forth above, a thickness that is greater or lesser than these ranges can also be applied to bearing cage **88**.

Lubricant layer **100** is deposited on top of bonding layer **98** in order to reduce friction between bearing cage **88** and the bearing balls **90** shown in FIG. **5**. Lubricant layer **100** can be composed of any known dry film lubricant material suitable for use with bearings in an x-ray tube environment. Silver is typically used as a lubricant when operating temperatures in the x-ray tube environment exceed 400 degrees Celsius and serves to minimize formation of adhesive junctions between bearing cage **88**, bearing balls **76**, **78**, and races **72**, **74**, **80**, and **82**. (shown in FIG. **4**) Being a relatively soft coating, silver is able to transfer from bearing cage **88** to either of the bearing balls and the races and maintain low friction therebetween. While silver has been described as a preferred lubricant layer **100**, it is also envisioned that other metallic lubricants can also be used such as gold, lead, or lead-tin. Furthermore, other solid lubricants may be added to form a "combination material" composed of, for example, silver and another lubricant, such as tungsten disulfides (WS2), molybdenum disulfide (MoS2), calcium fluoride (CaF2), CaF_2BaF_2 eutectics, and the like. Other advanced, high temperature, self-lubricating coatings can also be used for the bearings, such as a nano-alloyed carbon coating.

While lubricant layer **100** is shown deposited on top of bonding layer **98** in FIG. **6**, it is also envisioned that lubricant layer **100** could be directly applied to the carbon-carbon composite of bearing cage **88** without any bonding layer **98** therebetween.

It is also envisioned that, rather than bonding layer **98** and lubricant layer **100** being two distinct layers, a gradient type coating can be applied to bearing cage **88**. Referring now to FIG. **7**, a gradient coating **102** is shown deposited on the carbon-carbon composite of bearing cage **88** that is comprised of a bonding layer **98**, a transition layer **104**, and a lubricant layer **100**. The gradient coating **102** contains a gradual change in materials, such as from nickel to silver, that forms chemical bonds between adjoining layers and minimizes a coefficient of thermal expansion mismatch between adjacent coating layers, thus enhancing overall adhesion. For example, bonding layer **98** can be formed from 100% nickel to adhere to bearing cage **88**. Transition layer **104** is positioned above bonding layer **98** and contains a percentage of bonding material therein (e.g., 50% nickel) and a percentage of a lubricant material used to form lubricant layer **100** (e.g., 50% silver). The transition layer **104** is shown as a single layer in FIG. **7**, however, it is envisioned that transition layer **104** could be comprised of several layers, with each layer containing different percentages of bonding material and lubricant material so as to slowly transition from the bonding layer **98** to lubricant layer **100**.

The combination coating **96** of FIG. **6** and gradient coating **102** of FIG. **7** described above can be applied to bearing cage **88** in a variety of methods. That is, bonding layer **98**, lubricant layer **100**, and transition layer **104** can be applied via a number of suitable techniques. In one embodiment, chemical vapor deposition (CVD), including thermal CVD, metal-organic CVD, and plasma-enhanced CVD, is used to deposit a layer **98**, **100**, **104** onto the carbon-carbon composite material of bearing cage **88**. CVD uses a gas-phase precursor (e.g., silver halide or hydride) that is heated and flowed over the bearing cage **88** in a heated state to deposit bonding material and/or lubricant material to the bearing cage.

In another application method, a physical vapor deposition (PVD) technique is used to deposit a coating layer **98**, **100**, **104** onto the carbon-carbon composite material of bearing cage **88**. In PVD, the bonding and/or lubricant material to be deposited on bearing cage **88** is placed in an energetic, entropic environment, so that particles of material escape its surface. For example, in an ion-plating operation, bearing cage **88** is placed in an inert gas (e.g., argon), together with the bonding/lubricant material. A heating temperature and a low-voltage arc is applied to evaporate the metallic component of the coating material (e.g., silver), and then the ionized particles are accelerated to a high energy to coat bearing cage **88** via a bombardment of these accelerated particles.

In another technique, electroplating may be used to put on a layer, layers, or gradients of layers onto the carbon-carbon material of bearing cage **88**. Bearing cage **88** and the bonding/lubricant material are immersed in a solution containing one or more metal salts as well as other ions that permit the flow of electricity. A rectifier supplies a direct current to the bearing cage, causing the metal ions in solution to lose their charge and plate out the bearing cage **88**. As the electrical current flows, the bonding/lubricant material slowly dissolves and replenishes the ions in the solution.

In yet another PVD application technique, a sputtering technique is employed to deposit a layer **98**, **100**, **104** onto the carbon-carbon composite material of bearing cage **88**. In a sputtering coating technique, a thin film of bonding/lubricant material is deposited on bearing cage **88** by the ejection of atoms in a gas phase from a block of bonding/lubricant material called a target. The bonding/lubricant material atoms are ejected into the gas phase due to bombardment of the target material by energetic ions (e.g., argon plasma) and deposit on bearing cage **88** when positioned in a vacuum chamber.

It is also envisioned that various organic or inorganic based metallic pastes could be used to put on a layer, layers, or gradients of layers onto the carbon-carbon material of bearing cage **88**. For example, a platinum paste with ethyl cellulose and alpha termineol could be applied to bearing cage **88**. The paste could also contain oxides such as nickel oxide or titanium oxide, which could be subsequently be reduced to the base metal to form bonding layer **98** and/or lubricant layer **100**. A thermal spray or "cold spray" process may also be utilized to place a layer on the carbon-carbon bearing cage **88**. This material may be a metal or an oxide based material, such as NiO or TiO, that would be subsequently reduced.

In addition to the techniques set forth above, other various suitable coating techniques can also be implemented for applying a bonding layer **98** and lubricant layer **100** to the carbon-carbon composite bearing cage **88**.

Alternatively, or in addition to, the combination coatings **96**, **102** applied to bearing cage **88** as shown in FIGS. **6** and **7**, it is also envisioned that a lubricant can also be applied to races **72**, **74**, **80**, **82** and bearing balls **76**, **78** shown in the bearing assembly **58** of FIG. **4**, in order to reduce friction therebetween. Races **72**, **74**, **80**, **82** and bearing balls **76**, **78** may be comprised of tool steels typically used for bearing materials, such as Rex® 20, T5, T15 tool steels, and the like. Rex is a registered trademark of Crucible Materials Corporation, Solvay, N.Y. Bearing balls **76**, **78** may also be formed from a ceramic material. Referring now to FIG. **8**, a partial cross-sectional view of a base material **120** is shown from which the race and bearing balls are comprised. An adhesion layer **122** is deposited on base material **120**, and a lubricant layer **124** is deposited on the adhesion layer **122**. Lubricant layer **124** can be composed of silver, for example, or can further include a lubrication material other than silver such as WS2, MoS2, CaF2, CaF2BaF2 eutectics, nano-alloyed carbon, and the like. In this manner, the lubricant layer **124**, together with the adhesion layer **122**, enhances the lubrication performance and life of the base material **120** that forms the race and/or bearing balls.

As shown in FIG. **9**, a hardening layer **126** can also be included between adhesion layer **122** and lubricant layer **124**. The hardening layer **126** is formed of a material having a hardness greater than a base material **120** of the bearing race and the bearing balls. The hard material **126** can be formed of a hard particulate comprising one of TiC, TiN, TiAlN, diamond, silicon nitride, and silicon carbide. Alternatively, the hard material **126** can be formed of a hard coating comprising one of a monolithic nitride, a nano-multilayered nitride, a nickel-diamond coating, a ceramic, and a carbon and oxide coating with lubricating phase. For example, a nanocomposite TiC—C coating consists of nanocrystalline TiC grains embedded in an amorphous carbon matrix (nc-TiC/a-C), and offers low friction, high toughness, and thus excellent tribological properties. An improved wear resistance to the base material **120** is achieved by applying a hard material **126** layer on the base material **120** and applying lubricant **124** thereto.

FIG. **10** is a pictorial view of a CT system for use with a non-invasive package inspection system that can incorporate the x-ray tube **14** and bearing assembly **58** shown in FIG. **3**. Package/baggage inspection system **130** includes a rotatable gantry **132** having an opening **134** therein through which packages or pieces of baggage may pass. The rotatable gantry **132** houses a high frequency electromagnetic energy source **136** as well as a detector assembly **138** having scintillator arrays comprised of scintillator cells. A conveyor system **140** is also provided and includes a conveyor belt **142** supported by structure **144** to automatically and continuously pass packages or baggage pieces **146** through opening **134** to be scanned. Objects **146** are fed through opening **134** by conveyor belt **142**, imaging data is then acquired, and the conveyor belt **142** removes the packages **146** from opening **134** in a controlled and continuous manner. As a result, postal inspectors, baggage handlers, and other security personnel may non-invasively inspect the contents of packages **146** for explosives, knives, guns, contraband, etc.

According to one embodiment of the present invention, a bearing assembly mounted in an x-ray tube includes a bearing race, a plurality of bearing balls positioned adjacent to the bearing race, and a bearing cage positioned about the plurality of bearing balls.

According to another embodiment of the present invention, an imaging system includes an x-ray detector, an x-ray tube having a rotatable shaft, and a bearing assembly supporting the rotatable shaft. The bearing assembly further includes a bearing race, a plurality of rolling elements positioned adjacent to the bearing race, and a bearing cage configured to house the plurality of rolling elements.

According to yet another embodiment of the present invention, an x-ray tube bearing includes a raceway having an inner race and an outer race, a retainer positioned between the inner race and the outer race at each of a first end and a second end of the raceway, and a plurality of bearing balls within the retainer.

The present invention has been described in terms of the preferred embodiment, and it is recognized that equivalents, alternatives, and modifications, aside from those expressly stated, are possible and within the scope of the appending claims.

What is claimed is:

1. A bearing assembly mounted in an x-ray tube, the bearing assembly comprising:

a bearing race;

a plurality of bearing balls positioned adjacent to the bearing race; and

a bearing cage positioned about the plurality of bearing balls, wherein the bearing cage comprises a carbon-carbon composite material;

a bonding material deposited on the bearing cage; and a dry film lubricant deposited on the bonding material;

wherein the bonding material deposited between the bearing cage and the dry film lubricant has a thickness between 5 and 20 microns to fill in irregularities on a surface of the carbon-carbon composite bearing cage.

2. The bearing assembly of claim **1** wherein the dry film lubricant comprises at least one of silver, gold, lead, WS2, MoS2, CaF2, CaF2BaF2 eutectics, and amorphous carbon.

3. The bearing assembly of claim **1** wherein the bonding material comprises at least one of platinum, tungsten, molybdenum, chromium, nickel, silicon, copper, and titanium.

4. The bearing assembly of claim **1** wherein each of the plurality of bearing balls further comprises an adhesion layer and a lubrication layer deposited thereon.

5. The bearing assembly of claim **1** wherein the bearing race further comprises a lubrication coating deposited thereon.

6. The bearing assembly of claim **1** wherein one of the plurality of bearing balls and the bearing race further comprises a hard material deposited thereon having a hardness greater than a base material of the bearing race and a base material of the bearing balls.

7. The bearing assembly of claim **1** wherein the bearing cage further comprises a plurality of apertures therein to evenly space the bearing balls within the bearing cage and prevent contact between adjacent bearing balls.

8. An imaging system comprising:

an x-ray detector;

an x-ray tube having a rotatable shaft; and

a bearing assembly supporting the rotatable shaft, the bearing assembly comprising:

a bearing race;

a plurality of rolling elements positioned adjacent to the bearing race;

a bearing cage constructed of a carbon-carbon composite and configured to house the plurality of rolling elements; and

a combination coating deposited on the bearing cage, the combination coating including an interlayer applied to the bearing cage and a lubricant layer deposited on the interlayer;

wherein the interlayer has a thickness between 5 and 20 microns to fill in irregularities on a surface of the bearing cage and comprises at least one of platinum, tungsten, molybdenum, chromium, nickel, silicon, copper, and titanium.

9. The imaging system of claim **8** wherein the bearing race further comprises an inner race and an outer race.

10. The imaging system of claim **9** wherein the bearing cage is further configured to evenly space the plurality of rolling elements between the inner race and the outer race.

11. The imaging system of claim **8** wherein the lubricant layer comprises at least one of silver, gold, lead, WS2, MoS2, CaF2, CaF2BaF2 eutectics, and amorphous carbon.

12. The imaging system of claim **8** wherein at least one of the bearing race and the plurality of rolling elements further comprises a lubricant metal applied thereto.

13. An x-ray tube bearing comprising:

a raceway having an inner race and an outer race;

a retainer formed of a carbon-carbon composite material and positioned between the inner race and the outer race at each of a first end and a second end of the raceway;

a multi-layer coating deposited on the retainer, the multi-layer coating comprising a bonding layer deposited on the retainer and a dry film lubricating layer deposited on the bonding layer; and

a plurality of bearing balls within the retainer;

wherein the bonding layer deposited on the retainer has a thickness between 5 and 20 microns to fill in irregularities on a surface of the carbon-carbon composite retainer.

14. The x-ray tube bearing of claim **13** wherein the dry film lubricating layer comprises at least one of silver, gold, lead, WS2, MoS2, CaF2, CaF2BaF2 eutectics, and amorphous carbon.

* * * * *